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VEGETATIVE STABILIZATION OF MAGNA TAILINGS

Final Report on Grant 29-A-220-280

Utah State University, Logan, Utah 84322

F I N A L R E P O R T

To

KENNECOTT COPPER CORPORATION

Utah Copper & Metal Mining Divisions
Salt Lake City, Utah

From

UTAH STATE UNIVERSITY

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Project

"Consulting Services for Research on Vegetation to Stabilize
Tailings at Utah Concentrators"

Grant No. 29-A-220-280

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FINAL REPORT

This report covers the research conducted on Magna tailings in the laboratory, greenhouse and field by Utah State University for the period July 1, 1970 through December 31, 1973 under grant #20-A-220-280. Detailed progress reports have been submitted for 1970, 71, and 72. These data in addition to the 1973 data are summarized in this final report.

Introduction

The initial research on Magna and other Copper and Uranium tailings was supported by a grant to Utah State University from the U.S. Bureau of Mines, July 1, 1966. The first two years of the study involved greenhouse and laboratory activities. During the summer of 1967 a cooperative agreement was worked out between Utah State University and Kennecott wherein Kennecott would develop a test site to be used for the field phase of the Bureau of Mines contract. This field plot hereafter referred to as the Magna Site was developed on a two-acre plot of 25 year old inactive tailings on the southwest part of the tailings pond. Most of the tailings on the site were acid with a pH as low as 2.1.

The site was divided into four 1/2 acre units (A, B, C, D, see Figure 1) with dikes constructed of old acid tailings around each pond. A plastic liner and tile drains were placed in Ponds A and B. The site was prepared to receive the fresh tailings the summer of 1967, however, they could not be deposited because of the copper strike. The tailings were finally placed with the conventional pipe and spigot method the spring of 1968, with Ponds B and C receiving cycloned material and A and

D mill run tailings. Plantings were made the fall of 1968 and during 1969, with considerable data being collected. The Bureau of Mines contract was completed July 1, 1970. The research carried out under the Bureau of Mines contract was published in June 1972, in Utah State University Ag. Expt. Sta. Bul. #485, "Treatment of Mine Tailings to Promote Vegetative Stabilization," by Rex F. Nielson and H. B. Peterson.

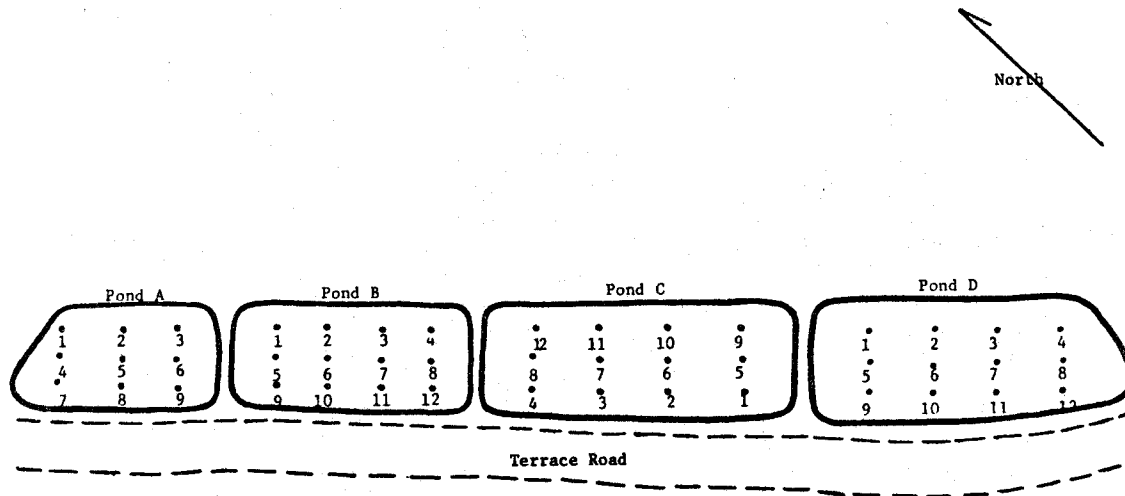


Figure 1. Magna Test Site

A research proposal was submitted to Kennecott by USU to continue the research on Magna tailings initiated by the Bureau of Mines contract. The proposal was accepted and a three-year contract was written, effective July 1, 1970.

The objective of the research has been to determine the feasibility of stabilizing Magna tailings with vegetation. This has necessitated a study of the chemistry of the material to identify toxicities, deficiencies and imbalances. Greenhouse and field studies have been used to confirm laboratory findings. The agronomic aspects of the problem have been researched by evaluating various plant materials and observing the effects of planting dates, fertilizers, irrigation and liming on plant growth and survival at the Magna Site.

Climate

The Magna Site is located in a semi-desert climate with hot, dry, windy weather during the growing season. Measurements made during these investigations show that plant growth is most rapid during April, May and the first half of June. By late June air temperatures have reached 104°F, with the soil at the 1 1/2 inch depth climbing to 117°F. At these temperatures grasses are severely affected and growth of many plants is retarded. During July and August high temperatures prevail for long periods of time raising soil temperatures throughout the entire root zone. By late August temperatures begin to cool off. Winter temperatures have not damaged plants during these studies.

Moderate to high velocity winds prevail from March through early June and can persist for several days. Gusts up to 30 miles per hour can be expected during any of the spring or early summer months. These high velocity winds can sand blast plants on unstabilized areas causing extensive damage in short periods of time. During late June, July and August total elapsed wind is markedly reduced, usually occurring as light afternoon breezes. Even though wind velocity is low, plants are rapidly desicated because of high temperatures during this period.

The precipitation at the Garfield Weather Station over the past 25 years has averaged 15.05 inches, with approximately half falling during April - September growing season. Examination of the data listed in Table 1 shows a large water deficit when comparing precipitation with pan evaporation. This deficit can only be corrected by using plants that make their growth in the spring, taking advantage of the winter moisture and cool temperatures, or by supplying irrigation water.

Table 1. Weather data 1970-72 (Inches).

	Precipitation*	Pan Evaporation**	Deficit
April	2.97	5.98	3.01
May	.87	9.40	8.53
June	1.05	11.62	10.57
July	.17	14.06	13.89
August	.56	12.71	12.15
September	1.68	8.52	6.84
Total	7.30	62.29	54.99

* Garfield

** Saltair Salt Plant

Salinity

One of the first problems encountered when attempting to grow plants on tailings is salinity. The primary source of this salt at Magna is from the water used in transport. The salt content of a system is measured as conductivity (in millimhos per centimeter) of the saturation extract. On agricultural soils with adequate water many crops are affected when the conductivity (ECe) is 4 to 8. Only the most salt tolerant crops will grow within the range of 8 to 16. When readings are in excess of 16 no crops survive.

The salinity of freshly deposited tailings is fairly uniform, however, this condition changes as soon as they begin to dry out. During the late spring and summer months the salts begin to accumulate at the surface with the greatest concentration being measured on the highest areas of the pond.

When a tailings pond becomes inactive, the salt distribution in the profile assumes a definite pattern. The four experimental ponds at the

Magna Site (see Figure 1) have been intensively monitored for the past four years. A summary of these data are listed in the Appendix, pages 34 through 49. Considerable variation exists in these data as might be expected, however, distinct patterns are evident. The data plotted for hole #5 Pond A shown in Figure 2 illustrates the salt concentration as a function of time and depth. This pond had a plastic liner and tile drain installed before the tailings were placed. The drainage system has been functional throughout the study as the salt concentrations have continued to decline each year. The leaching of the salt has been accomplished by limited irrigation and precipitation. For the past two years the salt levels have been sufficiently low for plants to grow reasonably well.

In contrast, the data shown in Figure 3 for hole #6 Pond B illustrates the salt profile in a lined pond where little or no leaching has occurred because of a non-functioning tile drain. This has been obvious since seasons with heavy precipitation produce a small lake on the pond that recedes only as it evaporates. After four years the salt concentrations have not changed. The current levels far exceed anything tolerable for plants. Examination of the data in Figure 3 show that the salt moves up and down in the profile as a function of precipitation and temperature. In the spring and early summer when moisture levels are highest, the salt levels in the surface six inches are lowest with the salt being concentrated at lower depths. By late summer or early fall the salt has migrated to the surface and is present in sufficient quantities to be visible. Under existing conditions with no drainage the salt cannot escape from the system.

The removal of salt from a tailings system depends on moisture from either irrigation and/or precipitation in amounts which are in excess

Pond A
Hole #5

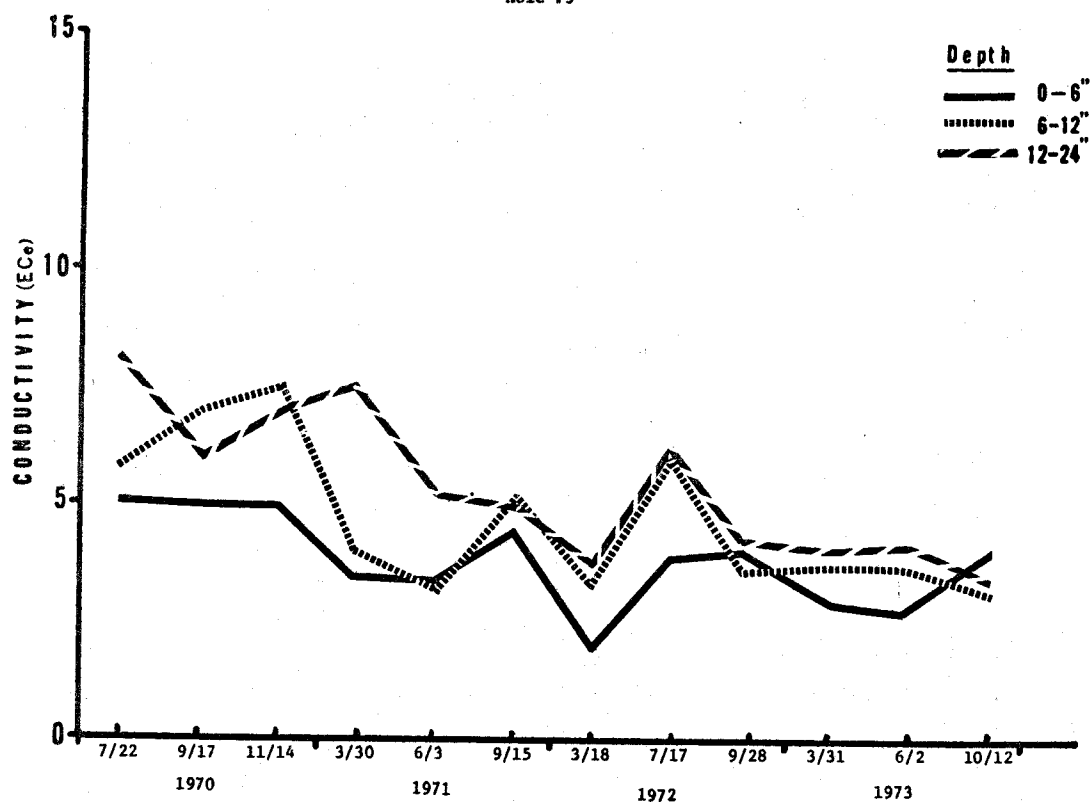


Figure 2. The Salinity of Tailings as Affected by Depth and Time.

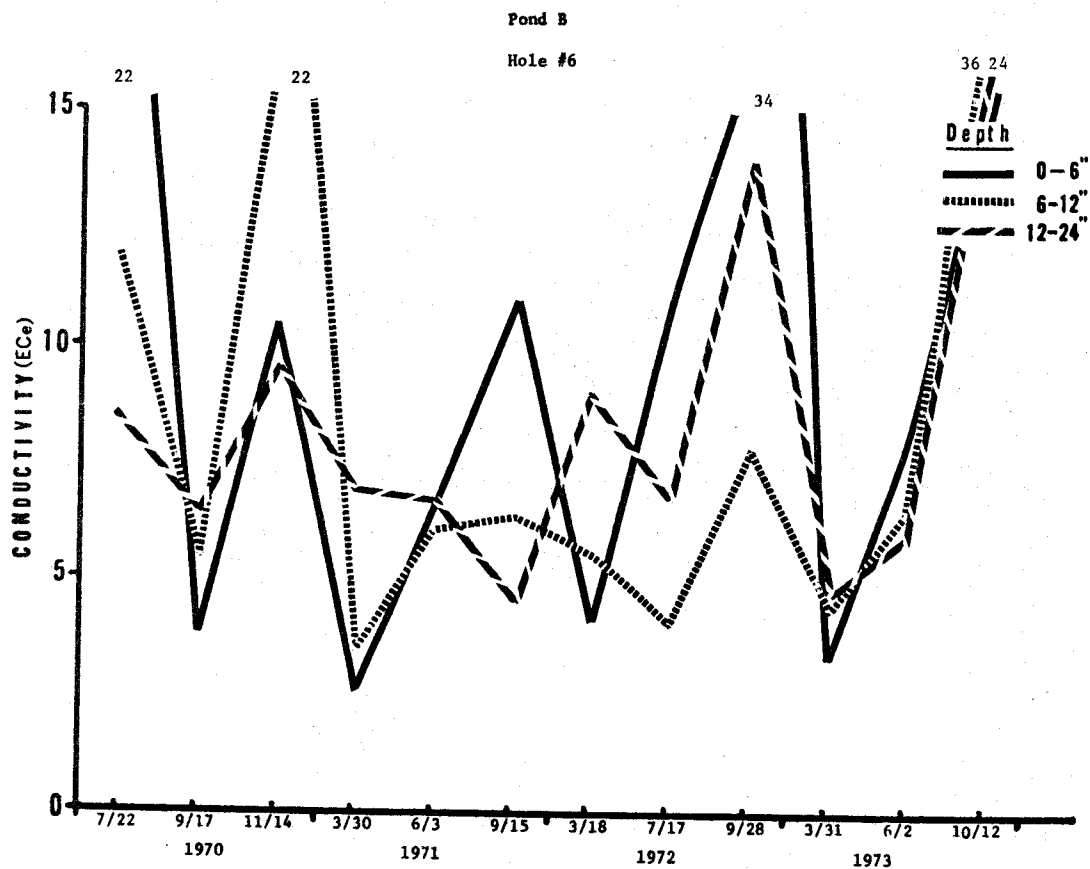


Figure 3. The Salinity of Tailings as Affected by Depth and Time.

of that lost from evaporation and used by plants.

It is recognized that the leaching evaluations made at the Magna Site where the tailings have been moved about in leveling do not apply directly to conditions that exist on the main pond. The slimes deposited in intermittent layers as the tailings are placed in the main pond will probably act as a barrier to downward movement of water in the leaching process.

When the main pond becomes inactive and is no longer flooded, it is likely that precipitation can leach the salts within a two to three year period provided drainage is not a problem.

The data shown in Figure 4 for hole #6 Pond D illustrates that salt levels were reduced to acceptable levels by precipitation the winter of 1969-1970. Salt removal can be rapidly accelerated by irrigation.

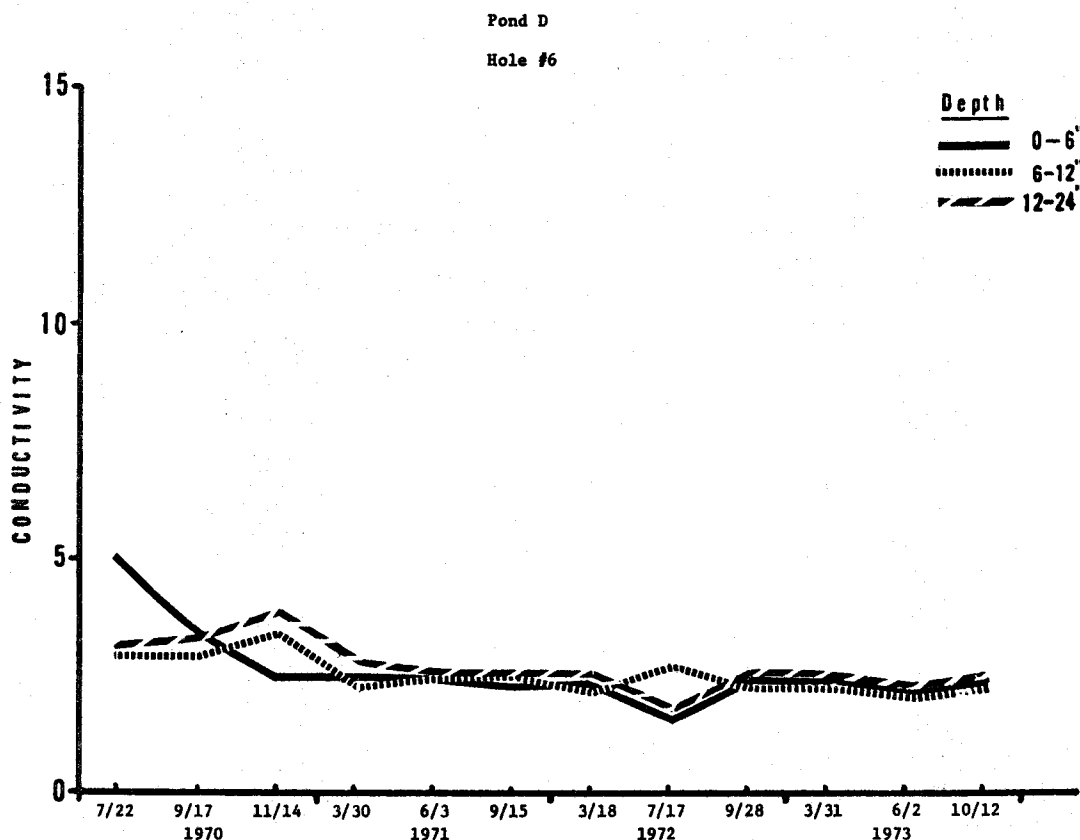


Figure 4. The Salinity of Tailings as Affected by Time and Depth.

Fertility

The plant nutrients in the tailings are very low, with nitrogen levels approaching zero. The phosphorus status is variable depending upon the area of the mine from which the ores are being processed. Some lots of tailings have been found to contain adequate phosphorus for plant growth, in general however, the tailings test low. Potassium is present in sufficient amounts for normal plant growth and no evidence has been found to suggest that minor element deficiencies exist, except those caused by imbalances and toxicities.

The nutrient needs of plants grown on tailings can be supplied by using commercial fertilizers at rates similar to those used on depleted agricultural soils. Applications of 50 to 75 pounds of N per acre each year in addition to 40 pounds of P per acre applied every second or third year has produced good plant growth. Fertilizer rates and frequency of application will be influenced by the stand density and kinds of the plants being grown. If irrigation is applied in amounts that result in the leaching of nitrogen, it is likely that more than 50 units of N per season will be required.

To date the use of legumes as a source of nitrogen for other plants grown on tailings has been disappointing. Normal production of legumes has only been achieved on plots where high rates of lime have been applied. If legumes are successfully grown, nitrogen fertilizer treatments could be reduced or eliminated.

It has been noted that plots producing good plant growth begin to develop an organic matter layer after several years. If this material is allowed to accumulate, it will make a contribution to the nutrient needs of the plants being grown. Since it will require at least five

years of good plant growth to have significant effect, it is likely that the 50 pounds of N per acre per year will be necessary during this period. After five years, depending on the amount and kind of vegetation produced, fertilizer treatments might be reduced or discontinued.

Acidification

The acidification of copper tailings is a relatively common occurrence, although it is site specific. The tailings at Kennecott operations at Chino are usually acid within two years after being deposited. In contrast, the tailings at McGill do not acidify even after 25 years. The main pond at Magna has shown no evidence of becoming acid, probably because it is active and new materials are constantly being added. As discussed previously, the area where the Magna Site was developed was on a 25-year old acid tailing. Except for this very old material, it had been assumed that acidification with Magna tailings was not a problem. Laboratory and greenhouse studies conducted during the Bureau of Mines contract have shown no evidence of these tailings becoming acid.

Field

The first signs of an acid problem was late in the summer of 1969 on Pond C when a small spot about five feet in diameter was observed where healthy plants were dying. Analysis of the material showed a pH of 3.0. By June of 1970 a considerable number of small yellow spots had developed on the surface of Pond C. These spots varied in size from 1 to 15 inches in diameter. Close inspection revealed they were shaped like a half-sphere with the flat side exposed to the surface. Samples collected from these sites showed pH values as low as 1.9. This was the first

documented evidence that Magna tailings, which are basic when they are deposited, could acidify in a period of two years.

By late summer of 1970 most of Pond C had gone acid resulting in the death of all plants in the affected areas. With the passage of time the acid problem spread to other ponds. A typical example is shown in Figure 5, where the pH has changed from 7.4 to less than 2 in four years. Not all sites become acid, however. In Figure 6 the pH has remained relatively constant. It is of interest to note that the two ponds containing cycloned tailings were the first to become acid. At the present time, the ponds with mill run tailings have some acid spots, but for the most part are neutral or basic.

Many researchers have shown that the acid problem is caused by the oxidation of pyrites. The first areas to go acid at Magna was at sites where the highest levels of pyrites tend to concentrate, that is immediately adjacent to the distribution spigot.

Greenhouse

A study was designed to measure the affect of increasing levels of pyrites on pH change and plant performance. A series of replicated experiments were set up in the greenhouse involving tailings from the test ponds treated with various rates of added pyrites with and without added lime. The test was initiated the winter of 1971-72 and continued through May. During the summer, the pots were allowed to dry out after which each pot was dumped, screened, and thoroughly mixed.

The pH data for the trials involving Pond B and D tailings are listed in Tables 2 and 3. It is evident that the pH of the Pond B material was markedly reduced by the addition of pyrites. The effect tends to be linear for both rates and time. Where lime was used with

Figure 5. The pH of Tailings as Affected by Depth and Time.

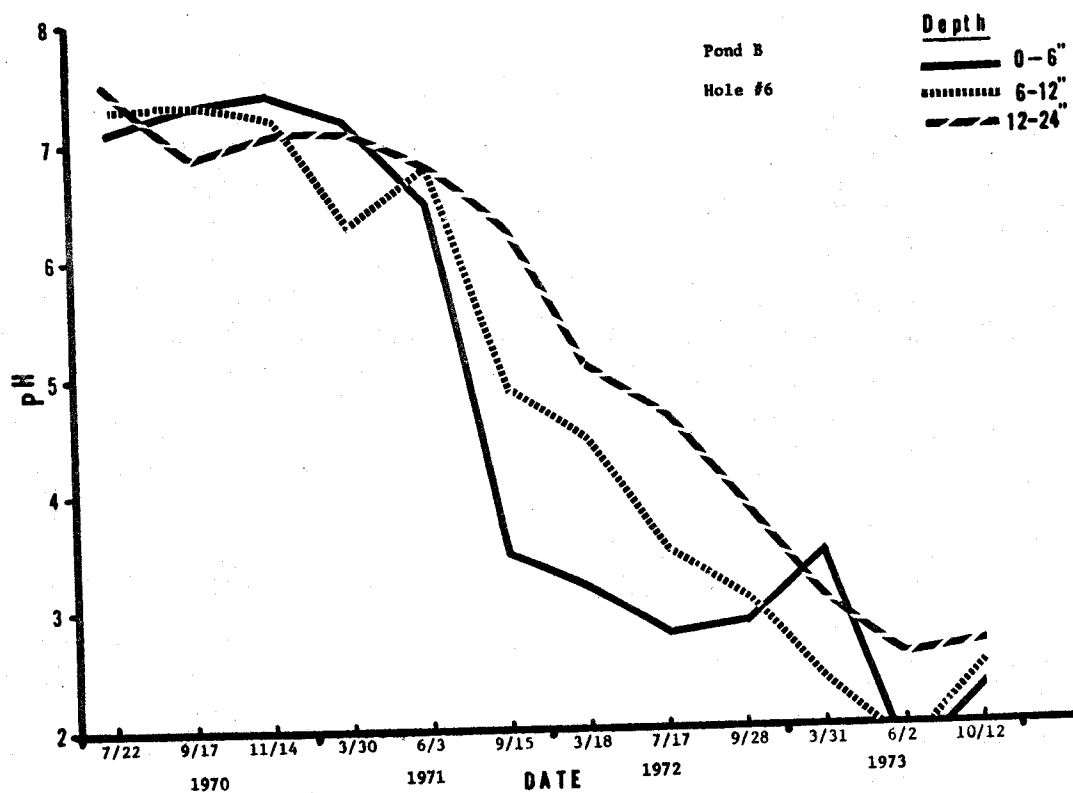


Figure 6. The pH of Tailings as Affected by Depth and Time.

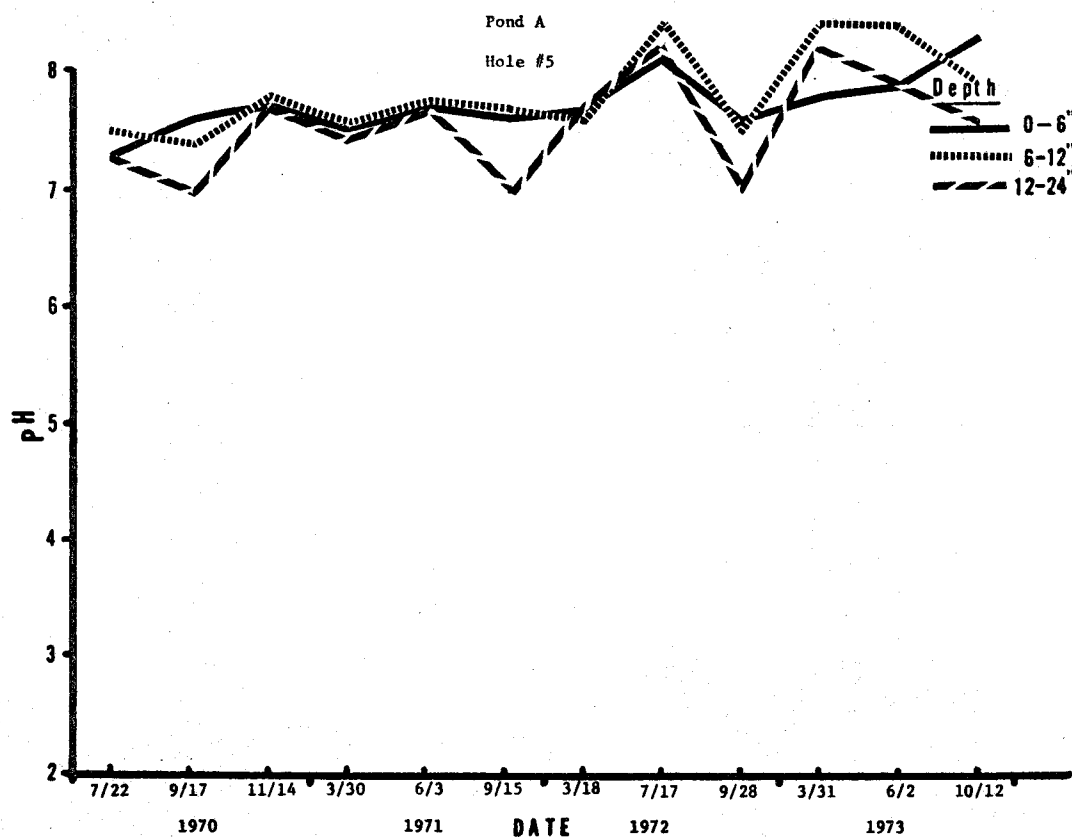


Table 2. The Effect of Added Pyrites and Lime on the pH of Tailings

Pond B Tailings pH						
% Pyrites	Pyrites			Pyrites + Lime		
	3/22	6/16	9/6	3/22	6/16	9/6
1	7.4	7.0	7.5	7.9	7.5	8.4
2	6.9	6.1	5.8	7.7	7.5	8.5
4	6.7	2.4	3.5	7.9	7.6	8.4
8	6.0	2.2	3.3	7.5	7.3	8.1
16	3.7	2.1	3.5	7.7	7.5	7.9

Planted January 20, 1972

Table 3.

Pond D Tailings
pH

% Pyrites	Pyrites			Pyrites + Lime		
	3/22	6/16	9/16	3/22	6/16	9/6
1	7.7	7.7	7.8	8.4	7.9	8.1
2	7.6	7.5	7.7	8.3	7.9	8.1
4	7.4	7.3	7.4	8.1	7.8	8.1
8	7.4	7.4	7.4	8.0	7.8	8.0
16	7.3	7.4	7.3	8.0	7.7	7.8

Planted November 10, 1971

the pyrites, the pH changes were not significant. It is of interest to note that Pond B tailings have a marked tendency to acidify under natural conditions at the test site. By way of comparison, tailings from Pond D were not affected by the addition of pyrites. This closely parallels the results at the Magna Site, as only a few spots on Pond D have gone acid. It is possible that the difference in performance of the two tailings sources is related to particle size and amounts of pyrites present or by some factor that inhibits oxidation. The increase of pH of limed pots on the September 6th date was related to the fact that the pots had been dumped, screened, and mixed prior to this reading making the lime present more effective.

The growth of plants was closely related to pH, with development being normal at levels of 6.5 or higher. At the lower pH ranges, all plants were severely affected or had died.

The greenhouse study was continued through the winter of 1972-73 with the original material in each pot being retained. The second year of the trial produced results quite different from those measured in 1972. The pH values of the tailing ranged from 8.0 to 8.7 irrespective of the amount of pyrites added. A possible explanation for these unexpected results relates to the fact that the organic matter that accumulated from the extensive roots in a pot can have an inhibiting effect on the oxidation of the pyrites. Further research will be required to better understand this problem.

Laboratory

A laboratory approach was developed to provide additional information on the oxidation of pyrites in tailings. Perfusion apparatus was

was constructed which allowed a sample to be continuously aerated by bubbling air and water through the sample chamber. It was possible to draw samples from the chamber without disturbing the operation of the equipment.

The first tests involved Pond C and Pond D tailings treated with five levels of pyrites. It was assumed at the time this phase of the study was implemented that oxidation of pyrites resulted primarily from microbial activity. Each chamber was inoculated with about ten grams of freshly oxidized tailings from the Magna Site. The data listed in Figure 7 shows the pH values for the five treatments over an 85-day period. The general slope of the graph is down, however, as pH was not significantly affected by the various pyrite levels. A similar run was made with Pond D tailings (Figure 8) with erratic results and no evidence of acidification.

Subsequent tests suggested that the oxidation was not resulting from a biological function, but primarily a chemical reaction. A series of trials using sterilized systems demonstrated oxidation could and did occur without the presence of microorganisms.

The data shown in Figure 9 illustrates the effect of added pyrites with and without inoculum perfused for 24 hours in a sand system. This further confirms that oxidation can occur without inoculum and that the difference in the two lines is caused by the acidity added with the inoculum.

Figure 10 illustrates the effect of varying rates of pyrites in a sand system perfused for 75 days. The 1/2 and 1 percent levels failed to

Figure 7. The Effect of Added Pyrites on pH.
(Pond C Tailings, Basic)

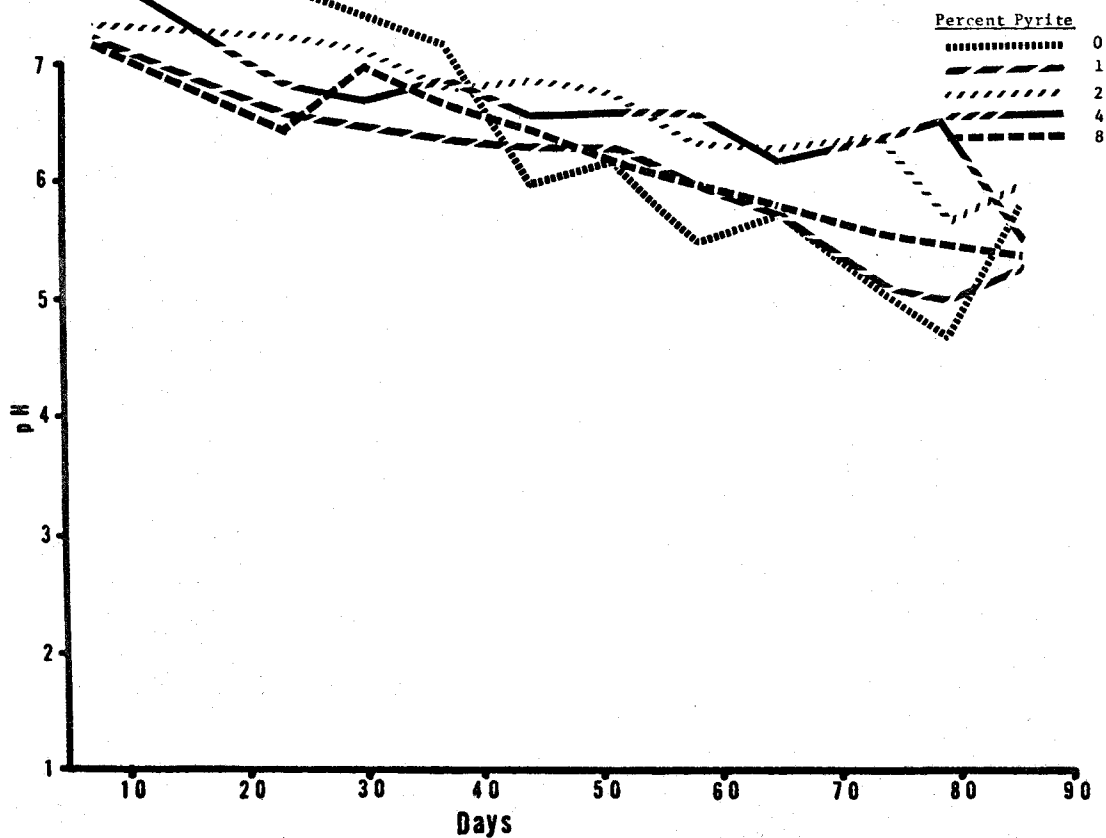


Figure 8. The Effect of Added Pyrites on pH.
(Pond D Tailings, Basic)

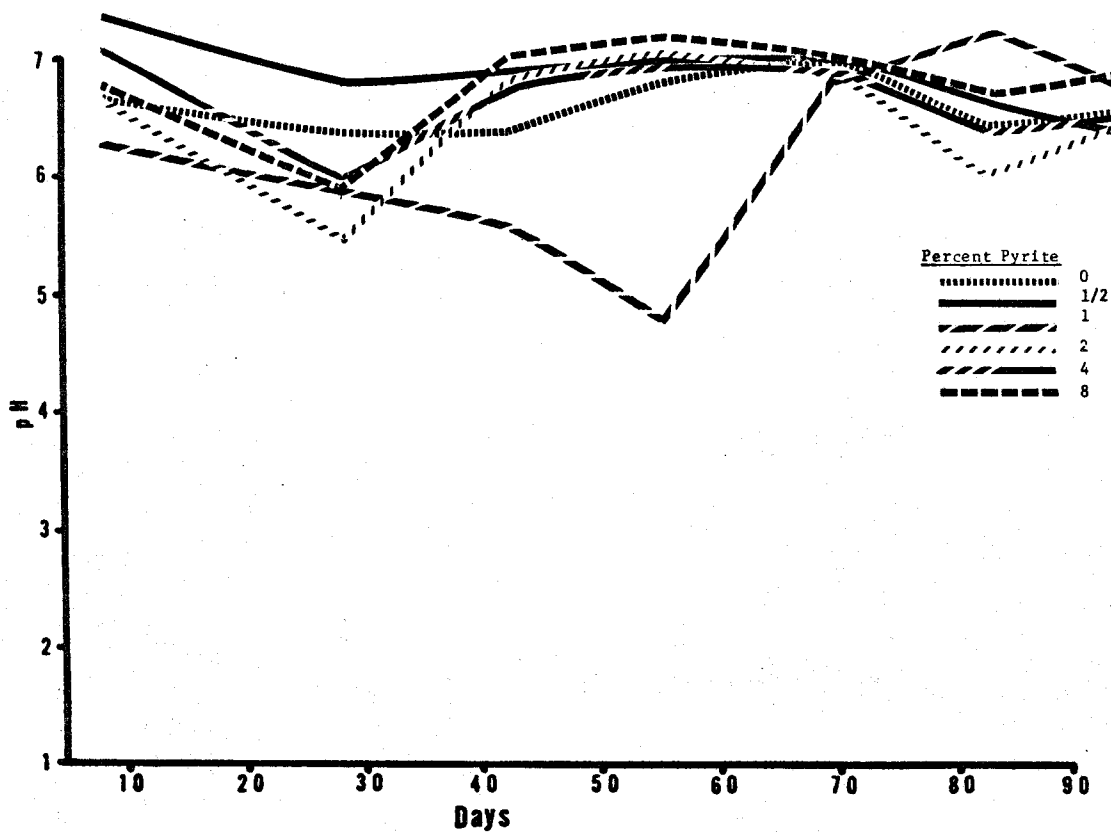


Figure 9. The Effect of Added Pyrites and Innoculum on the pH of Sand Perfused for 24 hours.

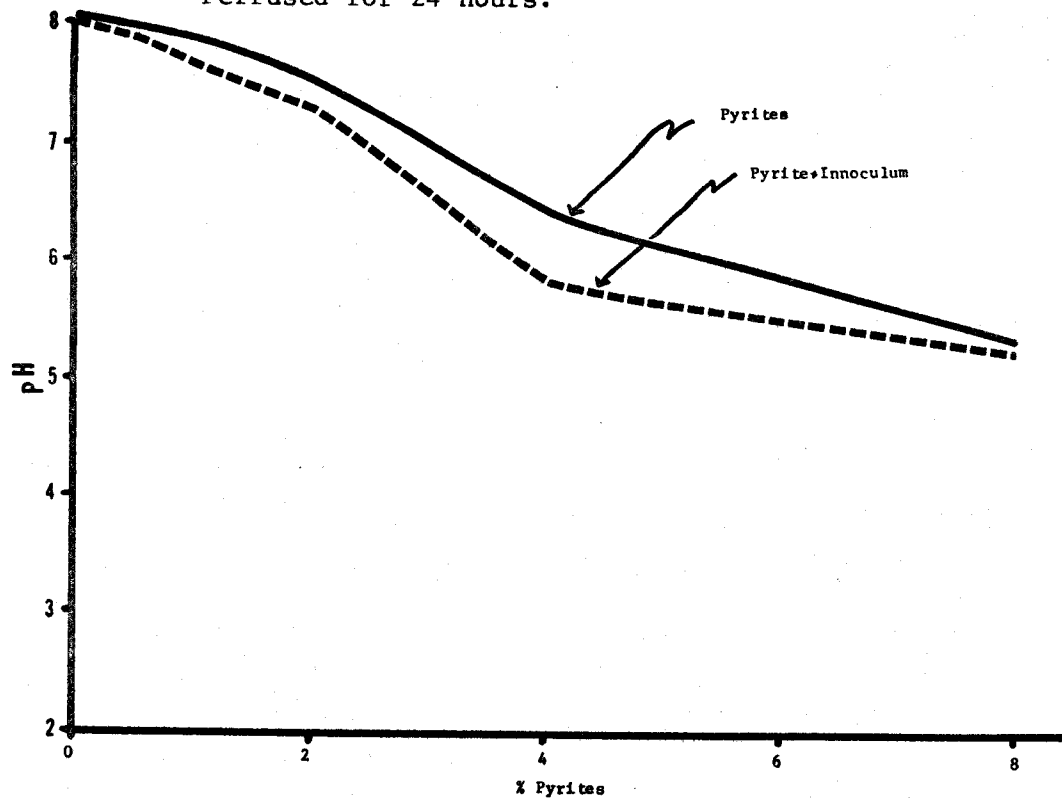
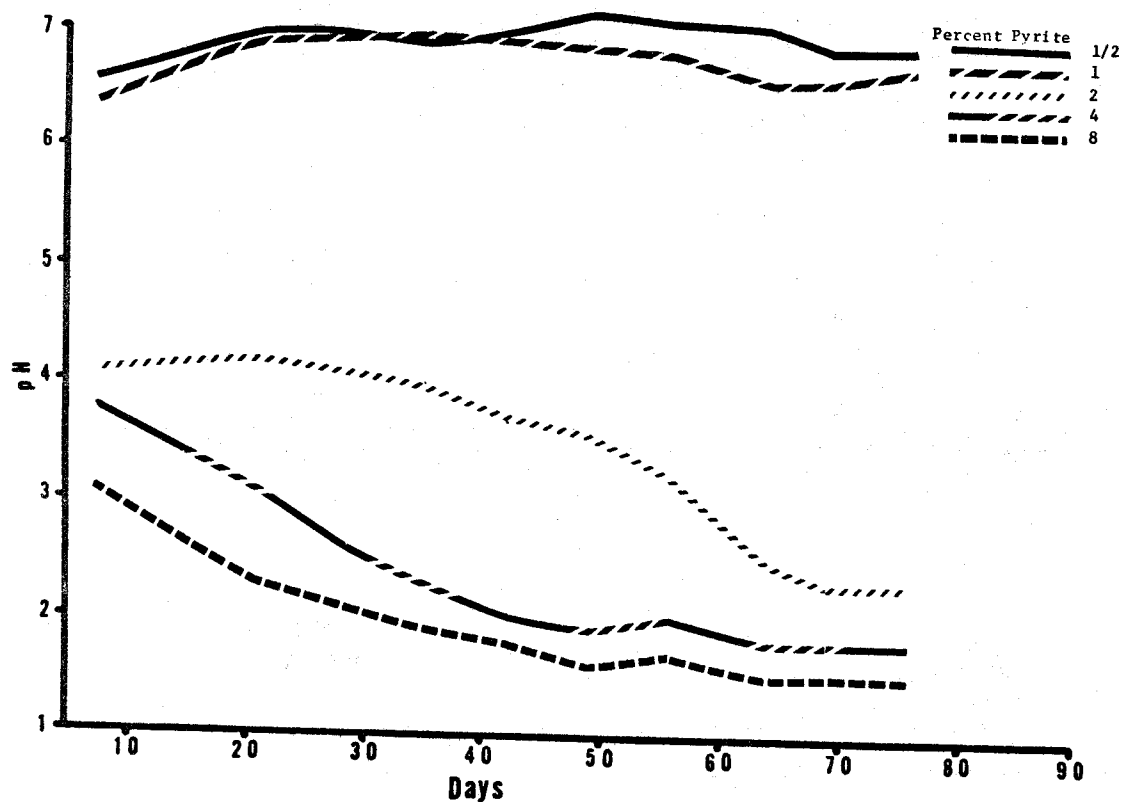


Figure 10. The Effect of Added Pyrites on the pH of Sand.



acidify with all other rates dropping to pH levels below 2.5. Numerous tests with pyrites in sand has demonstrated that the lowering of pH was directly related to the amount of pyrites added and that marked changes in pH occurred almost instantaneously after sand and pyrites were mixed with water.

Liming

The role of lime in altering soil acidity is well known so it was obvious that the low pH values resulting from the oxidation of the pyrites should be corrected by using lime.

Greenhouse

The first greenhouse study involved eight rates of lime mixed with 2 kilograms of acid tailings from Pond C. The mixture was saturated with water and allowed to react for a week after which additional water was applied to produce 50 ml of leachate. The data from the leachate, listed in Table 4, shows the striking effect of lime in increasing pH and reducing the solubility of copper. The pots were fertilized and seeded to Tall Wheatgrass and Sweet Clover. Plants did not survive where pH levels were below 6.3.

Table 4. The Effect of Various Rates of Lime on pH and the Solubility of Copper in Acid Tailings From Pond C

ppm Cu in Leachate

Lime (gms)	pH*	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Average
1	3.5	480	238	145	101	241
2	3.9	420	288	400	130	310
4	4.2	253	165	210	115	186
8	4.9	145	100	250	140	159
16	5.8	29	63	15	9	29
32	7.3	.8	.8	0	0	0
64	7.1	.5	1.2	0	0	0
132	7.6	.8	1.0	0	0	0

*pH of tailings after liming and before leaching.

Additional trials with acid tailings from Pond C suggested that lime rates in excess of 8 grams per pot (approximately four tons per acre) was necessary before plants could grow. The low rates of lime were adequate during the first few months of the study, but with time the tailings became acid and all plants died. At the termination of the experiment, 7 1/2 months after planting, the pH of the tailings had turned highly acid at all lime levels. This suggests that rates of lime as high as 64 tons per acre (132 gms. per pot) was not sufficient to maintain the pH above 7.

A second series of greenhouse studies was initiated to provide information on effects of high rates of lime mixed with basic tailings. The ratios ranged from 1:1 through 1:32, approximating what might be found in the field where heavy lime applications were plowed down. Nitrogen and phosphorus were added to all pots prior to seeding with a grass mixture of Tall Wheatgrass and Alta Fescue or to Sweet Clover.

Yield and pH measurements were recorded on two dates the first six months of 1972. In June the plants were allowed to dry up and die. In August each pot was dumped, the roots removed, and the original material mixed and returned to the pot. Nitrogen and phosphorus fertilizer was again applied to all the pots prior to planting. Yield data and pH measurements were made during the remainder of 1972 and into 1973. A summary of these data for Pond C tailings is shown in Table 5. Similar data were obtained from studies with Pond B and D material.

As might be expected, the pH of basic tailings changed very little during the more than two years of study. A tendency exists for the pH values to be lower where low rates of lime were used, however these differences are not significant.

Table 5.

The Effect of Different Ratios of Lime and Tailings on pH and Plant Yields in the Greenhouse. (Pond C Tailings.)

pH*

Ratio of Lime To Tailings	1972					1973	
	1/15	3/21	6/16	9/6	12/28	3/23	11/16
1-1	8.6	8.7	8.1	8.4	8.1	8.1	8.5
1-2	8.7	8.6	8.1	8.4	8.1	8.0	8.5
1-4	8.6	8.4	7.9	8.3	8.0	7.7	8.4
1-8	8.5	8.3	7.9	8.1	8.0	8.0	8.4
1-16	8.5	8.5	7.9	8.1	8.0	8.0	8.3
1-32	8.3	8.2	7.7	8.0	7.9	7.9	8.2

* Average of 6 reps

Yields in Gms/Pot Wt. **

Ratio of Lime To Tailings	Grass							Clover		
	1972		1973				Total	1972	1973	Total
	3/23	6/5	1/19	3/16	4/21	5/25		6/5	5/25	
1-1	50	50	21	21	27	25	194	25	31	56
1-2	60	60	21	21	35	27	224	25	46	71
1-4	60	60	16	19	32	23	210	35	48	83
1-8	55	60	17	16	28	31	207	40	42	82
1-16	40	55	15	16	21	26	173	25	39	64
1-32	35	50	17	18	25	22	167	40	36	76

** Average of 3 reps

Notes recorded on plant growth in addition to yield data suggest that grasses and Sweet Clover will grow in the various lime tailings ratio studied. However, the 1:1 ratio had a pronounced depressing effect on Sweet Clover. This was evident visually during the study and is further supported by the yield data. The physical properties of the tailings were materially improved with the lime, notably tilth and water holding capacity.

Field

The first lime tests at the Magna Site involved 10 ton per acre of spent sugar lime applied broadcast and not incorporated. This treatment had no measurable effect on pH or plant survival. In late summer of 1970 some 40 cubic yards of spent lime was obtained from the West Jordan Sugar Factory. This material was applied broadcast in strips on Ponds A, B, and D to a depth of 3 inches and then harrowed into the tailings to a depth of 4 to 6 inches. The areas were fall seeded to grass where good stands were obtained. Observations made in midsummer 1971 showed the limed strips on acid tailings were producing better plant growth than the unlimed areas. Samplings made the summer of 1971 indicate that the lime was mainly in the top four inches, with root activity being limited to the limed areas, especially on acid sites.

The limited success of liming in 1970 suggested a more ambitious program for the fall of 1971. Strips on Ponds A, B, and D were treated with 30 cubic yards each and the east 1/4 of Pond C with 60 cubic yards of lime. This material was plowed down and spring toothed into the tailings. The sites were then planted to rye and a mixture of grasses.

Good stands emerged the spring of 1972, however the acid tailings on Ponds B and C which were neutralized by the lime treatment in the fall of 1971, turned acid by early summer 1972 and most plants died.

Detailed sampling suggested that the lime was not uniformly distributed in the tailings even though the site had been plowed and tilled.

A new series of lime treatments was made the fall of 1972 on areas not limed previously in addition to retreating selected sites. Ponds A and B received 30 yards with Pond C receiving 90 yards. Since Pond C covers approximately 1/2 acre and less than 1/3 of the area has been limed, the accumulated lime rate on this site exceeds 500 cubic yards per acre. The 1972 treatments were double plowed and tilled at least four times with excellent incorporation of the lime. Plantings of rye and grasses were made in October resulting in good stands and growth during the 1973 season. All of the areas treated with high rates of lime the fall of 1972 measured pH values of 7 or greater during 1973. It should be noted however, that root proliferation was restricted to the limed portion of the tailings profile. The cover picture of this report was taken on the heavily limed section of Pond C.

Plant Evaluation

Tailings do not behave as normal agricultural soils. They are low in water holding capacity, devoid of plant nutrients, polluted with salts and heavy metals, and subject to wind erosion. Plants selected for use on tailings must be adapted to adverse conditions and also have some drought tolerance. The plants listed in Table 6 have been evaluated at the Magna Site.

Table 6. List of Plant Species Evaluated at the Magna Site.

Grasses and Legumes

Tall Wheatgrass (*Agropyron elongatum*)
 Intermediate Wheatgrass (*Agropyron intermedium*)
 Crested Wheatgrass (*Agropyron leptoarum*)
 Sodar Wheatgrass (*Agropyron riparium*)
Agropyron dasystachum
 Tall Fescue (*Festuca arundinacea*)
 Russian Wild Rye (*Elymus junceus*)
 Siberian Wheatgrass (*Agropyron riparium*)
 Wheat (*Triticum vulgare*)
 Rye (*Secale cereale*)
 Barley (*Hordeum vulgare*)
 Sorghum (*Sorghum vulgare*)
 Yellow Sweet Clover (*Melilotus officinalis*)
 Alfalfa (*Medicago sativa*)

Trees and Shrubs

Hybrid Poplar (*Populus x eugene*)
 European Sage (*Artemisia absinthium*)
 Green Ash (*Fraxinus pensylvanica*)
 Russian Olive (*Elaeagnus angustifolia*)
 Black Locust (*Robinia pseudo-acacia*)
 Siberian Pea Tree (*Caragana absorens*)
 Sand Cherry (*Prunus pumila*)
 Honey Locust (*Gleditisia triacanthas*)

Weeds*

Russian Thistle (*Salsola kali*)
 Kochia scoparia
 Bassia hyssopifolia
 Sunflower (*Helianthus annuus*)
 June Grass (*Bromus tectorum*)
 Tamarix (*Pentandra tamarix*)

*Seeds blown in from adjacent areas

Grasses have proven to be the best adapted of all the species planted. Tall Wheatgrass and Tall Fescue are the most hardy of the perennial grasses tested. The performance of Rye has been superior to either Wheat, Barley, or Sorghum. Sweet Clover has consistently made better growth than Alfalfa. The trees and shrubs have been disappointing with growth and survival generally poor. Russian Olive, Hybrid Poplar and European Sage are the only species to persist for more than one year.

It has been of interest to note the invasion of shrubs and annual weeds on sites where conditions have been made favorable for plant growth. These plants have all originated from wind blown seed

disseminated from adjacent areas. It is likely that many weedy plants indigenous to the area could persist on tailings.

The extent of plant growth is rigidly controlled by salinity, pH, moisture, fertility, heavy metal toxicity and exposure to erosion. Under the most favorable conditions all the plants tested will grow, however, when any of the above mentioned factors are adverse either singly or collectively they can bring about the death of all plants.

Wind Erosion

The physical characteristics of tailings are not significantly different from the sands of a desert and as such are subject to wind erosion. Dust originating from tailings continues to be objectionable to people, however, the sandblasting, blowing out, or burying of seedlings during high winds can often destroy plantings. During the early phases of this study an entire seeding of well-established fall planted grass was blown out in a matter of a few days during a spring windstorm.

When natural protection does not exist it is essential that the tailings must be stabilized during the time plants are being established. Excellent results have been obtained where Coherex was used at time of seeding. The degree of stabilization has been closely related to the amount of material used. Where higher rates were applied the sites continue to be stabilized for as long as four years. The use of straw or Tamarix limbs as a mulch has been effective in controlling erosion, however, costs are high.

Once a plant cover is developed, even though it may be relatively sparse, it has effectively controlled erosion at the Magna Site. It is probable that the erosion problems on the main pond will be more severe than those encountered on the test site.

Discussion

After more than six years of research under the Bureau of Mines and Kennecott contracts, the question, "can plants be grown on tailings?", can be categorically answered, yes. This infers that action will be taken to modify the tailings and apply proper amendments to support plant growth.

The fact that plants can be grown on tailings should not suggest, however, that vegetative stabilization should be pursued. The economics of the undertaking will have a marked effect on this decision. The cost of establishing and maintaining a plant cover can be reasonably well defined. Dollar values can be placed on seed, fertilizer, irrigation water, leveling, and chemical stabilization. The cost of lime as related to total acid producing potential of the pyrites is more difficult to determine. Current data suggest that large quantities of lime will be required to prevent the tailings from acidifying or to neutralize sites that have already gone acid. Information now available is not adequate to determine whether or not a site should be allowed to first become acid and then reclaimed with lime or treated with lime to prevent acidification. Data support both approaches.

The life expectancy of plants grown on tailings is not appreciably different from that found on soils. This assumes, however, that the tailings have been modified to support plants. The oldest plants growing

at the Magna Site have been established for four years. Where acidity is not a problem their present growth habits reflect available moisture and nutrient supply. There is no evidence to suggest that they will not survive indefinitely unless the environment changes.

The major deterrent to vegetative stabilization at Magna is the oxidation of pyrites resulting in a low pH and the solubilizing of heavy metals lethal to plants. Even when all other problems are corrected, plant cover cannot be sustained if pH values drop below 6. If plants are to be used to stabilize the Magna Pond it would be highly desirable to remove all the pyrites (within limits) from the tailings deposited during the last two years the pond is in operation. This would eliminate or at least minimize the acid problem. At the same time, the salt levels in the transport water could be reduced by using a minimum amount of recycled water supplemented with fresh sources rather than salty wells.

Alternative proposals are evident if plants are not to be used for stabilization. Observations made in September 1973 on the upper levels of the berm at the Magna Pond show acid spots are rapidly developing where the tailings have been exposed by stripping the borrow material. These acid spots have developed within two years after the tailings have been uncovered. It is highly probable that the Magna Pond will start turning acid within two years after becoming inactive if pyrites continue to be deposited. With present pyrite levels the total area could become acid within four years. Acid tailings form a crust and are less likely to blow than basic tailings.

It is conceivable that the acid crust could serve as a stabilizing medium. Kennecott has had experience with acid crusts at the Chino operations.

A second alternative would be to use chemical stabilization with Coherex or some other binding agent. This project can supply no long term data on the effects of chemical stabilizers.

The "island effect" of the Magna Site has encouraged increased bird and animal activity. Where good plant cover has become established mice, squirrels, and rabbits feed extensively throughout the year. Deer and pheasants have been present during the fall and winter months consuming considerable amounts of forage and seeds. On one occasion pheasants destroyed a sizeable seeding of fall grain. If and when the Magna Pond is vegetated a significant bird and animal population will likely develop.

Recommendations

The memorandum of understanding under which this contract has been expedited poses a number of specific questions to be answered in the final report. The following information attempts to fulfill this requirement.

The site preparation prior to planting should involve a smoothing operation to eliminate major undulations and channels. It will not be necessary to make the site level. If conditions permit it would be desirable to plow the area to a depth of 8 to 10 inches to mix up the slime and sand layers to encourage root and water penetration.

The plantings should be made with a disc drill placing grass or legume seeds from 1/2 to 3/4 inch deep. Larger seeds such as grain can

be planted to a depth of 2 inches. Where grasses or fall grains are being seeded plantings should be made in late October or early November before the area becomes frozen. Spring seedings of grass have always been inferior to fall plantings at the Magna Site. Legumes should be planted in late April or early May. Immediately following planting the site should be treated with Coherex or some other stabilizing agent to prevent wind erosion and protect seedlings.

Tall Wheatgrass, Alta Fescue, Rye, and Yellow Sweet Clover have been the best adapted of the plant species evaluated at the Magna Site. Russian Olive and Tamarix appear to be the best suited of the trees and shrubs studied. It should be noted that the weedy plants namely June Grass, Russian Thistle, Kochia, and Bassia are aggressive and readily invade new plantings. If seed is available these species will rapidly accelerate the establishing of a vegetative cover.

It will be necessary to apply a minimum of 50 pounds of Nitrogen (N) and 40 pounds of Phosphorus (P) fertilizer per acre prior to planting. This material should be incorporated for best results. Depending upon plant populations, moisture available and growth, the rates of N may need to be increased to 70 pounds per acre. Nitrogen treatments will be required annually for the first three years unless sufficient legumes are present to supply the nitrogen needs. Once plant populations are well established phosphorus treatments can probably be discontinued. After five years providing appreciable cover develops fertilizer applications may be discontinued.

When planted in the fall, grass has germinated, become established and persisted without irrigation on Pond D. Seedlings may do well or

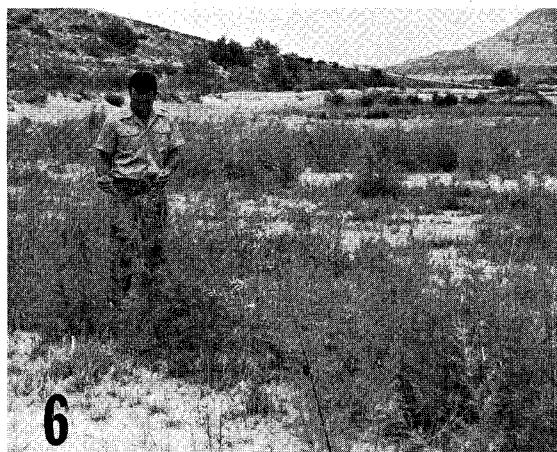
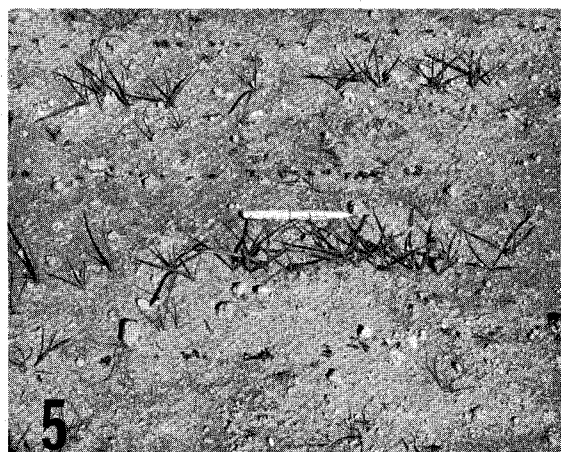
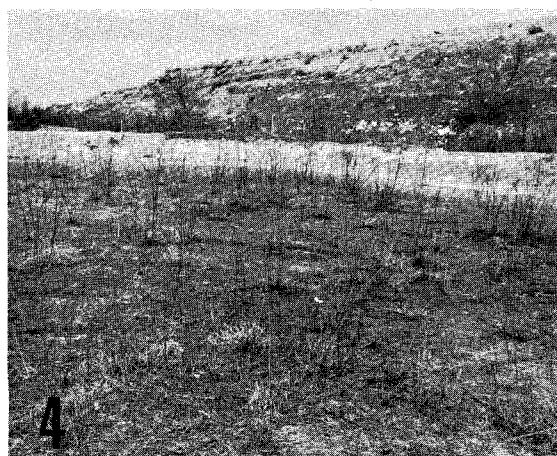
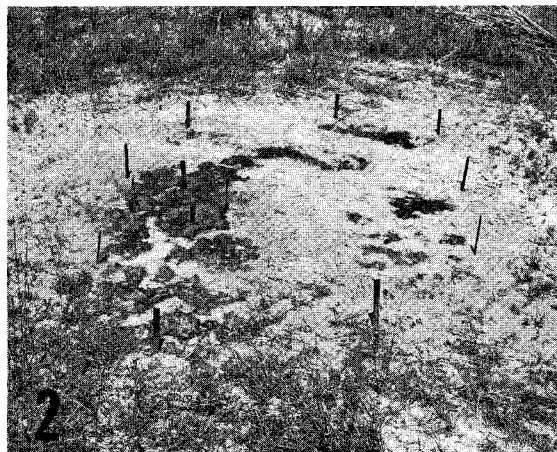
be total failures depending on the amount and patterns of rainfall. It is suggested that wherever possible irrigation be supplied the first year following seeding. Frequency and amounts of water to be applied will be influenced by temperatures and precipitation, however a weekly irrigation of 1/2 inch during May through August has been adequate during the past four years.

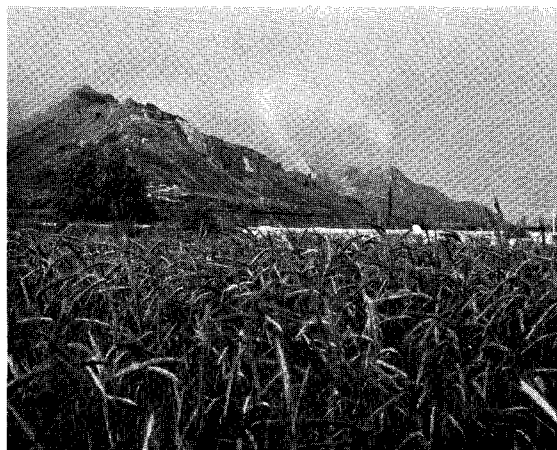
The foregoing recommendations have been on the premise that acidification was not a problem. This assumption is unfortunately not true at the present time with Magna Tailings. Unless pyrite concentrations are markedly reduced or eliminated the tailings will eventually go acid and destroy all vegetation. Heavy applications of lime, that is several hundred tons per acre, may be required to correct or prevent acidity in the tailings at the test site. To be effective the lime must be intimately mixed with the tailings to a depth of at least 12 inches. With information currently available it is not possible to accurately predict the amount of lime that will be required to correct or prevent the acidity that has or will develop from the oxidation of the various levels of pyrites in the tailings.

Where acid is not a problem and a proper environment is developed and maintained, plants can be expected to grow on tailings for an unlimited period of time.

Key to Photographs

1. Good stands of Tall Wheatgrass growing on Pond C with sprinkle irrigation. One year after this photo was taken the site went acid and all vegetation was killed.
2. Acid spot developing in an area formerly covered with vegetation. The small ring of stakes in the left center of the photo indicate the size of the acid spot when first observed. The outer ring of stakes show the extent of acid development two months later.
3. Good stands of grass in the spring following a fall seeding.
4. A three year old stand of Tamarix dying on an acid area of Pond C. The picture was taken one year after photo number 6.
5. Seedlings of grasses and legumes planted in the spring and irrigated. The germination of seed has not been a problem on tailings. With the onset of hot weather however, seedling mortality is often high even under irrigation. Plant survival has been lowest with spring seedings.
6. Tamarix plants that invaded a new seeding two years previously. Seed was blown in from adjacent areas.





Key to Photographs

1. Rodents burrow under vegetation produced on tailings the previous season. Animal populations at the Magna Site continue to increase as vegetative cover develops.
2. Rye with an understory of grass growing on a heavily limed area of formerly acid tailings on Pond C. This site was limed the fall of 1971, and a second application of lime was made the fall of 1972.
3. Considerable plant residue accumulates on sites where plants make good growth. This material helps develop a more favorable environment for other plants.
4. The effect of a straw mulch held in place by Tamarix limbs. The foreground was not treated while the area in the back half of the photo was mulched. The photo was taken three years after original treatment. Protective covers aid materially in establishing and maintaining vegetation.
5. A four year old planting of Tall Wheatgrass invaded by annual weeds. This site on Pond D was irrigated the first year after seeding.
6. The barren areas of Pond B demonstrate the effect of salinity and acidity on plants. Fall seeded grasses germinate, however they soon die the following spring.

Pond A

pH

Hole #	1970				1971		
	6/19	7/22	9/17	11/14	3/30	6/3	9/15
1-A	7.1	7.1	7.5	7.4	7.6	7.1	7.4
B	7.5	7.7	7.4	7.5	7.6	7.7	7.5
C	7.6	7.6	7.4	7.4	7.7	7.6	7.5
2-A	7.3	7.5	7.7	7.8	7.8	7.7	7.5
B	7.5	7.7	7.5	7.6	7.6	7.7	7.6
C	7.6	7.6	7.2	7.5	7.7	7.7	7.6
3-A	7.4	7.6	7.7	7.7	7.6	7.6	7.5
B	7.7	7.8	7.6	7.7	7.5	7.7	7.6
C	7.7	7.8	7.6	7.8	7.0	7.7	7.4
4-A	7.3	7.7	7.7	7.7	7.6	7.7	7.7
B	7.6	7.8	7.5	7.7	7.8	7.5	7.5
C	7.5	6.4	7.4	7.0	7.6	7.5	7.0
5-A	7.4	7.3	7.6	7.7	7.5	7.7	7.6
B	7.6	7.5	7.4	7.8	7.5	7.7	7.7
C	7.4	7.3	7.0	7.7	7.4	7.7	7.0
6-A	7.6	7.6	7.7	7.8	7.5	7.4	7.4
B	7.7	7.6	7.7	7.7	7.6	7.6	7.4
C	7.2	7.3	7.3	7.4	7.8	7.5	7.3
7-A	7.4	7.3	7.0	7.5	7.0	7.4	4.5
B	7.6	7.4	5.4	7.4	7.5	7.3	4.9
C	7.6	7.6	6.6	5.1	4.5	6.4	6.0
8-A	7.5	7.5	7.0	7.3	6.8	7.4	3.2
B	7.7	7.5	6.8	7.6	7.3	7.2	3.0
C	7.6	7.5	7.0	7.6	5.3	7.1	3.1
9-A	7.6	7.6	7.7	7.5	7.4	5.6	6.3
B	7.7	5.0	7.7	7.4	7.0	3.7	3.6
C	7.7	7.3	7.5	7.6	7.2	5.9	6.0

Pond A

pH

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	7.5	8.0	7.3	8.0	8.0	7.3
B	7.4	8.0	7.6	7.7	8.0	7.9
C	7.4	7.8	7.7	7.7	7.8	8.0
2-A	7.8	8.3	7.9	7.7	8.8	8.5
B	7.5	7.9	7.1	8.1	7.7	8.0
C	7.4	7.9	7.5	7.8	7.9	8.1
3-A	7.8	7.8	7.8	7.8	7.9	7.8
B	7.7	7.8	7.9	7.9	7.9	7.7
C	7.5	7.8	7.9	7.9	8.0	7.8
4-A	7.6	7.8	7.5	7.7	7.9	8.0
B	7.5	7.8	7.3	7.8	7.8	7.6
C	7.5	7.3	6.8	8.0	7.8	7.6
5-A	7.7	8.1	7.6	7.8	7.9	8.3
B	7.6	8.4	7.5	8.4	8.4	7.9
C	7.7	8.2	7.0	8.2	7.9	7.5
6-A	7.6	8.0	7.8	8.1	8.0	7.8
B	7.6	7.6	7.6	8.0	8.1	7.9
C	7.5	7.8	7.5	7.8	7.9	7.7
7-A	7.0	4.8	4.2	6.6	6.6	4.3
B	4.2	4.2	3.2	2.6	2.3	2.8
C	6.1	5.4	4.5	3.2	3.0	2.4
8-A	7.3	4.0	6.8	7.5	7.7	6.9
B	7.0	6.7	3.1	6.1	3.0	2.7
C	4.5	3.5	3.4	3.6	2.5	2.5
9-A	6.9	6.6	7.5	7.7	7.4	7.4
B	3.4	4.3	5.0	7.9	7.7	7.0
C	4.9	4.5	4.3	7.5	3.6	7.2

Pond B

pH

Hole #	1970				1971		
	6/25	7/28	9/17	11/14	3/30	6/3	9/15
1-A	5.9	6.3	4.9	7.4	5.7	4.6	3.1
B	7.4	7.2	7.0	7.5	6.8	6.7	4.0
C	7.6	7.3	7.1	7.5	7.1	7.2	5.9
2-A	6.8	6.8	6.4	5.1	3.1	4.4	3.2
B	7.4	7.1	6.4	5.1	5.6	4.6	3.3
C	7.5	7.3	7.0	7.0	6.8	6.6	6.3
3-A	6.9	6.6	6.5	7.0	4.0	4.0	3.5
B	6.9	6.6	5.9	6.7	5.7	4.4	3.2
C	7.6	7.1	7.1	7.4	6.7	6.7	6.2
4-A	7.0	7.3	7.7	8.1	7.0	5.7	5.7
B	7.0	7.0	7.7	6.9	5.4	5.2	7.5
C	7.7	7.3	7.1	7.3	6.7	6.6	7.7
5-A	6.9	5.5	5.8	7.0	3.7	3.2	3.7
B	7.6	7.2	7.3	7.6	6.4	4.2	4.6
C	7.8	7.4	7.2	7.4	7.3	6.2	6.1
6-A	7.3	7.1	7.3	7.4	7.2	6.5	3.5
B	7.6	7.3	7.3	7.2	6.3	6.8	4.9
C	7.9	7.5	6.9	7.1	7.1	6.8	6.3
7-A	7.3	7.2	7.7	7.8	7.5	7.1	6.9
B	7.4	7.1	8.1	7.8	7.7	7.3	7.3
C	7.4	7.4	7.1	7.5	7.7	7.2	7.1
8-A	7.4	7.2	7.6	7.5	7.3	7.2	7.4
B	7.6	7.5	7.9	7.9	7.5	7.5	8.0
C	7.5	7.4	7.4	7.8	7.6	7.6	7.9
9-A	7.8	7.7	7.8	8.2	8.1	7.9	7.5
B	7.7	7.5	7.5	7.8	7.9	7.7	7.4
C	7.7	7.5	7.6	7.8	7.6	7.5	7.5
10-A	7.0	7.4	7.5	8.2	7.6	7.6	6.4
B	7.7	7.5	7.6	8.0	7.7	7.5	6.9
C	7.7	7.5	7.6	7.8	7.7	7.6	7.5
11-A	7.3	7.5	8.3	7.7	7.8	7.5	7.4
B	7.6	7.1	8.0	7.5	7.8	7.5	7.3
C	7.0	7.4	7.6	7.8	7.6	7.5	7.4
12-A	7.6	7.7	8.3	8.3	7.7	7.6	7.5
B	8.0	7.7	8.4	8.2	7.7	7.6	7.3
C	7.4	7.6	7.8	7.8	7.4	7.5	7.4

pH

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	2.1	2.8	3.1	5.1	2.0	2.4
B	2.2	3.2	3.3	2.8	2.3	3.0
C	4.0	6.7	3.1	5.3	3.1	3.7
2-A	2.8	2.8	3.1	4.3	2.0	2.4
B	2.8	2.7	3.0	2.7	2.2	3.6
C	3.5	3.5	3.8	2.5	2.6	2.7
3-A	3.0	2.7	3.2	2.7	2.2	2.3
B	2.8	3.0	2.9	3.3	2.1	2.6
C	4.0	4.5	3.4	3.4	2.8	2.6
4-A	7.2	3.4	7.6	7.5	7.5	7.4
B	8.0	7.4	7.3	7.6	7.5	8.0
C	7.6	4.6	7.1	7.6	2.5	7.2
5-A	2.8	3.7	3.2	3.0	7.9	3.2
B	3.4	3.2	3.5	2.7	4.0	3.0
C	4.8	3.8	3.2	3.8	2.4	2.7
6-A	3.2	2.8	2.0	3.5	1.7	2.3
B	4.5	3.5	3.1	2.4	1.8	2.5
C	5.1	4.7	7.2	3.1	2.6	2.7
7-A	7.0	5.3	3.6	2.7	1.9	2.3
B	7.9	7.2	5.0	3.5	3.8	3.2
C	7.6	6.7	6.5	6.5	5.7	4.3
8-A	7.9	7.4	7.2	7.6	7.5	5.8
B	7.9	8.1	7.0	4.7	7.4	2.5
C	8.0	7.5	8.0	7.8	7.8	7.4
9-A	8.2	7.4	7.9	7.7	5.5	3.0
B	7.9	7.6	7.6	4.5	5.4	3.4
C	7.8	7.3	7.8	6.6	6.9	4.1
10-A	7.2	4.0	4.0	2.4	3.0	2.4
B	7.6	6.3	7.2	6.1	6.7	4.0
C	7.6	6.8	7.3	7.0	7.3	7.6
11-A	7.9	7.2	4.3	7.6	3.6	2.7
B	7.8	7.2	4.9	7.0	2.8	2.9
C	7.8	6.8	6.3	6.8	4.3	2.7
12-A	8.2	7.1	7.8	8.0	7.6	7.7
B	8.1	7.4	7.9	8.0	8.1	7.5
C	8.1	8.1	7.7	8.1	8.0	7.8

pH

Hole #	1970			1971		
	8/5	9/17	11/14	3/30	6/3	9/15
1-A	4.5	5.4	6.5	3.8	3.8	7.0
B	4.2	3.5	2.7	2.6	2.9	6.8
C	7.0	4.7	4.4	4.1	3.1	3.0
2-A	4.2	4.5	2.6	3.5	3.0	3.1
B	6.3	6.3	2.9	2.6	2.9	3.8
C	6.8	6.0	3.1	2.8	2.9	5.8
3-A	7.1	7.0	6.5	6.7	3.1	3.2
B	7.3	7.1	4.1	7.3	2.9	3.1
C	7.3	7.2	6.6	7.2	3.8	2.9
4-A	2.6	2.9	2.8	2.7	2.9	3.2
B	2.5	2.6	2.6	2.7	2.8	3.0
C	3.9	2.5	2.8	2.7	3.1	2.9
5-A	6.5	4.2	3.1	2.9	3.0	7.0
B	6.9	6.7	6.6	4.0	3.5	7.5
C	7.1	7.0	7.3	6.3	3.4	7.4
6-A	3.7	5.2	4.9	3.3	3.1	3.2
B	6.9	5.6	6.3	6.2	3.2	3.6
C	6.5	4.6	3.4	3.8	3.2	3.0
7-A	7.2	6.8	7.0	5.6	3.1	6.2
B	5.0	5.7	3.5	5.4	3.0	4.0
C	6.4	3.8	4.2	3.0	2.9	3.3
8-A	3.3	3.7	7.2	3.0	3.0	3.0
B	5.1	4.7	7.6	3.1	3.2	3.2
C	6.9	6.9	7.5	4.7	5.5	5.2
9-A	6.9	6.8	5.5	5.2	3.9	3.9
B	7.1	6.3	7.2	7.0	5.4	7.2
C	4.5	7.0	5.5	7.2	4.3	6.8
10-A	4.6	3.0	3.0	4.5	3.3	3.7
B	7.0	5.2	4.3	4.5	5.3	4.4
C	7.3	7.2	7.2	6.3	6.9	6.2
11-A	7.7	7.3	7.2	6.6	7.6	6.5
B	7.3	7.2	7.3	7.0	7.5	4.4
C	7.5	7.2	7.0	7.2	7.3	6.5
12-A	7.2	7.0	7.2	6.6	5.4	6.3
B	7.1	7.3	4.9	6.8	6.8	4.2
C	7.5	7.4	7.6	7.4	7.2	6.9

pH

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	7.6	5.9	7.7	8.2	8.0	7.8
B	7.0	7.8	7.5	8.0	7.7	7.4
C	7.4	3.7	4.3	7.3	7.4	6.9
2-A	4.5	2.8	7.8	8.0	8.0	8.0
B	3.3	2.9	6.3	7.5	8.2	6.9
C	2.8	2.6	4.2	7.2	7.2	4.0
3-A	3.1	2.7	4.8	7.1	2.2	2.6
B	2.5	2.9	3.1	1.9	2.1	2.9
C	2.5	2.5	2.9	2.2	1.8	2.5
4-A	2.7	2.5	3.1	2.4	2.0	2.7
B	2.8	2.5	2.9	2.5	2.3	2.9
C	2.7	2.5	3.3	2.4	2.1	2.8
5-A	6.5	6.3	7.4	7.6	7.1	7.9
B	8.0	7.9	7.2	7.5	7.0	7.8
C	7.8	3.3	7.1	7.5	6.2	6.9
6-A	3.4	2.8	7.9	7.9	7.4	
B	3.5	4.5	7.5	8.0	7.6	4.1
C	2.7	2.9	7.1	8.3	5.6	3.6
7-A	3.8	2.8	3.2	2.1	1.9	3.5
B	2.6	2.9	3.0	2.5	2.6	2.6
C	2.5	2.5	3.4	2.2	2.2	2.7
8-A	2.5	2.6	3.5	2.3	1.9	3.0
B	2.3	2.5	2.6	2.3	1.8	2.5
C	3.4	3.4	3.1	2.3	1.8	2.4
9-A	7.0	4.7	7.1	7.8	7.4	7.6
B	7.9	3.6	7.7	7.5	7.2	7.1
C	8.0	6.7	7.3	7.4	6.8	7.1
10-A	2.9	3.2	7.7	7.9	7.3	7.3
B	2.6	2.7	7.7	8.0	7.4	7.1
C	4.6	4.2	7.2	7.2	3.4	7.2
11-A	4.5	4.2	6.6	4.8	2.4	4.8
B	2.5	4.5	4.4	2.4	3.0	2.3
C	2.9	5.3	4.9	3.4	2.6	3.1
12-A	6.2	4.5	4.2	3.0	1.9	2.5
B	5.4	3.6	3.7	2.3	2.2	2.4
C	6.4	6.1	6.3	3.7	3.3	3.1

pH

Hole #	1970				1971		
	6/30	7/28	7/19	11/14	3/30	6/3	9/15
1-A	7.7	7.8	7.6	7.8	7.4	7.2	7.2
B	7.5	7.6	7.4	7.7	7.4	7.2	7.4
C	7.7	7.7	7.6	7.8	7.5	7.4	7.5
2-A	7.5	7.5	7.4	7.7	7.1	7.5	7.5
B	7.7	7.7	7.6	7.8	7.2	7.5	7.4
C	7.8	7.6	7.5	7.6	7.5	7.3	7.5
3-A	7.5	7.4	7.5	7.5	7.1	7.4	7.9
B	7.6	7.6	7.4	7.6	7.2	7.3	8.0
C	7.8	7.6	7.6	7.7	7.6	---	7.6
4-A	7.3	7.3	7.4	8.0	7.8	8.0	7.5
B	7.4	7.6	7.5	7.8	7.5	7.8	7.5
C	7.6	7.5	7.7	7.8	7.6	7.9	7.5
5-A	7.5	7.5	7.6	7.8	7.5	7.7	7.4
B	7.6	7.5	7.6	7.9	7.2	7.6	7.4
C	7.7	7.6	7.6	7.8	7.4	7.6	7.5
6-A	7.4	7.6	7.5	8.0	7.3	7.5	7.4
B	7.7	7.3	7.4	7.9	7.4	7.4	7.5
C	7.5	7.3	7.5	7.5	7.3	7.6	6.9
7-A	7.3	7.3	7.5	7.4	7.3	7.6	7.8
B	7.6	7.5	7.6	7.5	7.4	7.6	7.8
C	7.6	7.6	7.6	7.5	7.5	7.5	8.0
8-A	7.5	7.3	7.4	8.1	7.8	8.1	6.8
B	7.6	7.5	7.2	8.0	7.7	7.6	7.0
C	7.2	7.4	7.5	7.9	7.5	7.8	7.4
9-A	7.4	7.6	7.6	7.8	7.3	7.7	7.5
B	7.5	7.5	7.4	7.8	7.2	7.5	7.3
C	7.5	7.5	7.5	7.8	7.3	7.5	7.1
10-A	7.6	7.6	7.6	7.8	6.8	7.6	6.4
B	7.5	7.7	7.3	4.2	3.2	4.3	3.5
C	7.5	7.3	7.4	3.3	3.9	4.5	4.9
11-A	7.6	7.3	7.4	3.9	7.2	6.8	7.3
B	7.5	7.5	6.2	2.6	7.3	7.2	7.3
C	7.3	7.5	6.2	3.9	7.4	7.4	5.5
12-A	7.7	7.2	7.3	7.5	7.6	8.0	6.7
B	5.1	6.9	6.7	7.0	7.2	7.7	7.2
C	5.2	5.8	4.7	4.1	4.9	6.5	7.4

pH

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	7.4	6.7	7.1	7.9	6.7	7.5
B	7.5	6.9	7.3	7.7	7.3	7.4
C	7.5	7.4	7.2	7.6	7.4	7.5
2-A	7.7	6.9	7.2	7.6	7.3	7.3
B	7.4	6.5	7.3	7.6	7.2	7.1
C	7.5	7.3	7.5	7.5	7.2	7.5
3-A	8.0	7.7	7.6	7.5	7.6	7.1
B	7.3	8.0	7.9	8.1	8.2	8.0
C	7.9	7.8	7.4	7.4	8.1	7.7
4-A	8.0	7.5	7.5	7.3	8.2	7.9
B	7.9	7.2	7.7	7.5	8.1	7.6
C	7.8	7.3	7.5	7.5	7.9	7.6
5-A	7.7	7.3	7.5	7.8	8.0	7.7
B	7.7	7.1	7.6	7.7	7.8	7.5
C	7.7	6.7	7.5	7.7	7.8	6.5
6-A	7.8	6.7	7.5	7.7	7.7	7.4
B	7.6	7.1	7.6	7.7	7.6	7.5
C	7.7	7.2	6.9	7.6	7.0	7.5
7-A	7.9	7.6	7.6	7.8	7.6	7.7
B	8.3	8.2	8.0	7.9	7.5	7.7
C	8.2	7.9	7.6	8.2	7.8	7.6
8-A	8.0	7.4	7.2	7.7	7.5	7.8
B	8.0	7.3	7.2	7.7	7.7	7.5
C	7.8	7.4	7.3	7.7	7.6	7.8
9-A	7.9	7.3	7.5	7.7	7.6	7.5
B	7.7	7.4	7.6	7.4	7.6	7.3
C	7.6	7.4	7.3	7.7	7.4	6.9
10-A	7.4	3.9	6.9	6.8	7.4	6.4
B	2.9	3.1	5.4	3.1	7.2	4.6
C	3.3	4.3	4.8	2.5	7.6	6.8
11-A	7.6	7.2	7.2	6.8	7.2	7.2
B	7.8	7.7	7.7	7.5	7.6	7.3
C	7.7	7.2	7.4	7.2	7.2	4.8
12-A	7.6	3.6	7.0	6.9	3.6	6.8
B	3.4	6.3	4.5	2.6	2.1	3.7
C	4.5	7.4	6.7	7.0	3.1	3.2

Pond A
Conductivity (ECe)

Hole #	1970				1971		
	6/19	7/22	9/17	11/14	3/30	6/3	9/15
1-A	6.0	5.6	4.0	5.0	2.6	2.7	13.6
B	8.5	7.6	8.5	7.5	3.7	4.2	6.5
C	9.5	9.0	9.0	9.0	7.5	5.2	5.8
2-A	15.0	15.0	4.0	4.0	2.6	3.8	1.4
B	15.5	13.2	5.0	6.5	4.5	3.6	5.0
C	9.5	10.8	8.0	11.0	9.5	5.2	5.0
3-A	4.5	3.8	4.0	3.7	3.2	2.5	3.6
B	6.0	5.7	6.0	6.5	3.6	3.0	5.2
C	5.5	6.8	4.5	6.5	5.5	4.2	4.2
4-A	8.5	10.2	5.0	4.5	3.8	3.4	5.6
B	7.5	7.8	5.5	7.0	6.3	3.6	6.8
C	9.5	9.1	8.0	7.5	8.3	5.5	6.0
5-A	4.5	5.1	5.0	5.0	3.5	3.4	4.5
B	6.5	5.8	7.0	7.5	4.0	3.3	5.1
C	10.0	8.2	6.0	7.0	7.5	5.2	5.0
6-A	3.5	4.3	2.8	3.4	2.8	2.9	3.6
B	5.5	4.5	2.2	4.5	2.8	2.7	4.4
C	9.0	6.2	7.0	7.0	5.8	4.5	5.0
7-A	9.0	11.0	5.0	6.5	3.4	4.5	9.4
B	7.5	8.2	7.5	8.0	4.8	5.2	5.4
C	9.5	8.0	10.0	8.0	14.0	5.9	6.2
8-A	6.0	6.6	7.5	3.4	3.0	3.4	11.4
B	6.5	4.8	5.0	7.5	3.0	2.7	16.0
C	6.0	5.4	6.0	6.0	4.8	2.7	13.0
9-A	2.8	3.1	2.6	2.7	2.4	3.1	4.6
B	3.5	3.4	1.6	3.7	3.0	4.3	5.4
C	4.5	4.1	3.3	4.0	3.0	3.2	3.3

Pond A

Conductivity (ECe)

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	2.2	2.3	4.0	2.0	1.7	2.7
B	2.6	2.4	2.9	2.5	1.6	3.0
C	3.1	4.0	2.6	3.0	3.2	3.6
2-A	2.5	3.5	3.0	3.4	1.3	2.0
B	2.8	3.2	3.6	4.5	3.0	3.2
C	4.9	2.3	3.4	7.4	3.0	3.2
3-A	1.5	2.0	3.8	2.8	3.6	8.1
B	2.7	3.2	3.5	2.9	3.6	7.5
C	2.6	3.4	2.8	3.0	3.8	5.6
4-A	2.6	3.7	3.3	2.6	2.7	2.7
B	3.0	5.2	4.4	2.6	2.6	2.3
C	3.7	5.9	3.3	3.9	3.2	3.0
5-A	2.0	3.9	4.0	2.9	2.7	4.0
B	3.3	6.0	3.6	3.8	3.8	3.1
C	3.8	6.1	4.2	4.0	4.1	3.4
6-A	2.5	2.0	2.3	2.8	3.0	4.8
B	2.4	2.6	1.9	3.4	3.7	5.2
C	2.7	4.5	3.8	3.5	3.6	6.5
7-A	2.7	8.1	8.0	3.2	3.3	6.2
B	3.8	5.9	9.0	5.5	4.5	8.0
C	4.3	4.1	3.0	5.1	5.0	19.0
8-A	1.5	10.0	7.5	2.9	3.4	5.3
B	3.1	4.5	8.1	3.6	4.5	9.5
C	4.5	6.3	5.1	5.8	5.0	22.0
9-A	2.8	4.0	9.0	2.9	4.5	8.3
B	3.6	4.0	6.7	3.8	3.8	6.5
C	3.5	5.5	7.0	4.5	5.2	5.0

Pond B

Conductivity (ECe)

Hole #	1970				1971		
	6/25	7/28	9/17	11/14	3/30	6/3	9/15
1-A	4.6	8.6	2.8	3.0	3.0	3.5	17.0
B	5.6	11.5	4.0	3.8	3.4	5.1	8.7
C	15.0	24.0	13.0	14.0	8.0	11.0	9.9
2-A	3.3	4.8	3.5	3.3	5.5	7.0	24.0
B	5.7	9.5	5.0	7.5	10.5	9.0	9.4
C	13.6	16.0	13.0	26.0	14.0	14.0	10.0
3-A	2.8	4.0	5.5	3.6	3.7	4.3	9.5
B	2.8	5.9	3.6	4.5	3.2	3.5	7.7
C	12.0	16.0	5.5	5.5	5.2	5.8	4.6
4-A	4.1	6.4	1.9	1.5	1.1	2.5	3.0
B	3.0	4.1	2.8	4.5	1.3	3.8	6.5
C	10.8	16.0	3.8	3.8	1.7	5.9	6.0
5-A	9.0	38.5	7.5	3.5	2.4	6.1	6.9
B	7.7	7.4	3.9	5.0	2.7	4.5	7.7
C	6.8	10.2	13.0	23.0	10.0	4.0	4.0
6-A	7.8	22.2	3.9	10.5	2.7	6.5	11.0
B	5.6	12.0	5.5	22.0	3.5	6.1	6.4
C	8.4	8.6	6.5	9.5	7.0	6.8	4.6
7-A	15.0	21.0	4.5	4.0	3.1	10.0	10.0
B	11.2	8.2	2.5	11.5	7.3	15.0	8.8
C	9.0	7.8	23.0	10.5	11.0	1.3	5.9
8-A	9.7	23.0	7.5	2.8	1.9	2.2	4.3
B	7.5	5.6	5.0	4.8	3.6	3.9	22.0
C	9.9	10.7	12.0	11.5	6.5	8.5	8.2
9-A	5.1	6.6	4.5	1.3	0.8	1.0	2.6
B	5.1	5.1	8.0	4.5	0.8	1.5	10.8
C	8.4	5.6	5.5	5.0	3.0	3.6	3.9
10-A	3.0	11.3	4.0	0.7	0.8	1.2	2.3
B	4.2	5.6	7.0	2.6	1.7	1.2	3.1
C	6.7	5.1	7.0	3.4	2.7	4.5	4.3
11-A	2.2	4.3	2.6	1.1	1.1	3.2	1.5
B	3.6	4.1	3.2	3.5	1.1	2.1	1.8
C	5.8	4.7	6.0	3.2	5.0	5.2	3.0
12-A	2.0	4.6	3.0	0.6	0.8	1.7	3.7
B	2.2	4.1	1.4	1.3	1.5	1.6	3.4
C	4.3	4.2	3.2	4.7	4.8	3.5	4.3

Conductivity (ECe)

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	4.7	5.9	22.0	2.4	5.5	4.7
B	3.8	6.9	7.6	3.8	4.5	18.0
C	5.5	9.5	11.0	5.2	6.3	27.0
2-A	4.1	9.0	20.0	2.7	5.7	5.3
B	6.9	9.5	7.5	3.5	8.1	7.8
C	22.0	18.0	16.0	8.1	23.0	20.0
3-A	4.6	7.0	28.0	3.8	7.0	5.4
B	6.7	5.7	9.0	3.6	7.2	4.4
C	8.9	5.5	8.5	6.9	8.0	20.0
4-A	2.8	37.0	9.7	2.7	5.5	4.6
B	4.2	7.6	22.0	3.2	5.0	8.7
C	5.9	10.0	9.5	5.3	8.5	10.0
5-A	4.0	5.5	22.0	3.1	4.2	8.3
B	6.0	6.0	6.1	4.9	5.8	24.0
C	7.9	5.8	9.5	6.5	8.0	16.0
6-A	4.2	11.0	34.0	3.4	8.0	15.5
B	5.7	4.1	7.7	4.5	6.5	36.0
C	9.0	6.9	14.0	4.8	6.0	24.0
7-A	3.3	4.5	9.5	3.4	8.6	28.0
B	7.5	7.0	7.5	5.0	6.2	34.0
C	8.1	5.8	9.7	8.0	9.6	24.0
8-A	4.2	28.0	8.2	2.8	5.0	6.5
B	6.5	7.1	5.5	3.5	5.7	18.0
C	10.4	5.0	24.0	6.0	7.5	8.6
9-A	1.2	2.4	2.2	1.5	2.2	3.0
B	2.6	2.4	2.7	2.6	2.4	4.0
C	2.7	2.4	2.8	2.8	2.2	4.5
10-A	1.5	2.2	1.9	4.2	3.1	5.6
B	2.0	3.7	2.4	3.1	2.7	4.5
C	2.8	2.4	2.5	3.2	2.8	2.8
11-A	2.2	4.8	4.2	3.0	3.5	9.5
B	2.8	2.2	3.1	2.9	3.9	9.7
C	5.5	3.9	3.1	3.2	4.8	9.9
12-A	1.7	10.0	6.5	2.8	4.6	15.0
B	2.6	5.8	9.0	3.4	3.6	7.8
C	4.6	5.0	4.2	4.7	4.0	7.3

Conductivity (ECe)

Hole #	1970			1971		
	8/5	9/17	11/14	3/30	6/3	9/15
1-A	8.1	2.8	2.7	2.9	3.6	6.1
B	8.1	4.5	4.5	5.0	6.0	5.5
C	4.2	4.0	4.9	3.2	4.5	11.0
2-A	5.9	3.2	5.0	3.1	8.0	13.5
B	3.2	2.9	5.5	5.5	7.9	12.2
C	2.8	3.2	8.5	5.3	7.1	4.4
3-A	5.0	2.6	2.6	2.5	7.5	11.2
B	4.3	3.8	3.1	2.4	5.8	11.4
C	3.7	5.0	3.6	2.5	3.3	9.6
4-A	8.6	9.0	4.4	5.5	9.2	10.5
B	9.8	6.5	5.4	5.4	6.5	9.6
C	8.6	9.5	6.9	5.5	4.9	24.0
5-A	5.4	3.0	4.8	4.8	8.8	7.2
B	3.2	6.0	5.0	3.7	6.3	4.5
C	5.3	4.0	5.0	2.8	7.0	3.6
6-A	5.2	3.8	2.8	3.2	9.0	36.0
B	4.1	5.5	3.8	3.3	5.0	24.0
C	3.4	3.7	5.2	3.6	4.5	10.4
7-A	3.9	2.9	2.8	2.6	8.8	2.8
B	3.1	3.8	3.8	2.8	7.1	5.0
C	3.4	4.5	5.5	3.8	6.5	8.7
8-A	11.0	4.5	0.9	3.3	6.0	8.9
B	4.8	4.0	3.5	3.8	7.2	8.1
C	4.2	7.0	4.5	3.1	3.0	3.9
9-A	3.3	2.8	2.8	2.6	4.9	8.0
B	3.1	5.0	2.9	2.6	2.8	7.4
C	5.0	3.8	3.8	3.0	3.6	5.9
10-A	6.4	5.0	4.6	2.6	8.2	5.9
B	4.5	4.0	4.4	3.0	3.1	8.5
C	4.1	5.0	5.2	2.9	3.4	3.6
11-A	2.4	2.1	1.6	1.5	1.7	2.7
B	3.0	3.9	2.7	2.4	2.6	3.3
C	3.8	2.8	3.2	2.6	3.2	2.9
12-A	4.2	3.0	0.8	1.0	2.4	1.6
B	3.1	5.0	2.8	2.4	2.5	2.8
C	5.3	5.5	4.6	3.0	2.8	3.8

Conductivity (ECe)

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	3.4	7.1	8.5	3.0	4.2	6.5
B	3.0	6.0	8.0	3.4	3.8	7.7
C	4.2	8.5	10.0	3.4	3.8	5.4
2-A	2.5	24.0	8.0	3.3	4.6	4.8
B	3.0	7.5	3.8	3.8	4.8	18.0
C	3.8	8.6	4.8	4.0	4.4	9.8
3-A	2.8	20.0	10.0	2.9	5.6	3.1
B	4.8	7.5	20.0	5.7	7.4	10.0
C	5.1	9.5	9.0	5.0	7.0	8.1
4-A	3.0	8.0	9.5	2.2	5.2	5.2
B	1.8	5.2	8.5	2.2	3.6	6.4
C	3.5	6.9	8.2	3.8	3.8	6.0
5-A	3.0	17.0	9.0	3.1	4.6	7.1
B	5.6	7.5	9.5	4.0	4.5	21.0
C	5.4	22.0	4.2	6.0	4.8	8.0
6-A	3.4	28.0	7.1	3.3	4.0	
B	3.4	5.5	9.9	4.4	3.8	4.7
C	4.5	7.2	2.3	3.7	3.2	4.0
7-A	2.7	14.0	27.0	4.0	9.2	5.5
B	3.8	9.5	9.2	3.7	6.5	9.0
C	5.4	7.5	6.7	3.7	4.0	6.2
8-A	4.2	15.0	6.5	4.1	15.0	9.2
B	2.9	6.2	14.0	4.1	8.0	7.9
C	3.7	5.0	7.0	4.0	6.5	10.0
9-A	2.7	13.0	9.5	2.8	4.0	3.6
B	4.4	13.0	5.6	3.6	4.2	4.0
C	5.4	6.8	4.3	3.8	4.2	5.0
10-A	3.8	5.8	5.6	3.0	4.3	5.1
B	4.9	20.0	7.6	5.0	5.1	5.1
C	2.6	5.0	3.1	3.6	14.0	5.5
11-A	2.8	3.8	2.8	2.6	7.6	3.1
B	4.4	3.6	4.7	4.0	6.5	6.4
C	3.5	2.6	2.6	4.0	4.4	6.6
12-A	2.0	3.8	5.6	2.4	8.5	5.2
B	2.4	4.0	4.9	4.0	6.5	6.4
C	3.0	3.6	3.4	3.2	4.5	20.0

Conductivity (ECe)

Hole #	1970				1971		
	6/30	7/28	7/19	11/14	3/30	6/3	9/15
1-A	4.8	7.2	4.0	2.8	2.6	2.6	3.6
B	4.0	5.5	5.0	4.2	3.0	3.5	4.4
C	5.4	5.3	6.5	5.6	4.0	4.3	4.6
2-A	2.7	2.8	2.7	4.1	2.5	2.5	2.2
B	3.4	3.8	3.7	2.6	2.6	2.6	2.6
C	4.5	4.7	4.0	4.7	3.2	3.2	2.8
3-A	2.6	2.8	2.8	3.2	2.5	2.6	3.8
B	2.2	3.4	3.0	3.2	2.6	2.6	5.6
C	4.6	4.0	3.6	4.0	2.9	---	3.0
4-A	2.2	2.9	2.4	3.3	3.2	5.2	2.7
B	2.8	3.1	2.6	3.5	3.0	3.0	3.2
C	3.2	3.4	3.0	3.9	3.4	3.3	3.4
5-A	4.3	5.1	3.4	2.5	2.5	2.5	2.3
B	3.8	5.1	4.5	2.9	2.9	2.5	2.2
C	3.7	4.3	6.0	4.0	3.2	2.6	2.4
6-A	2.7	2.8	2.6	3.3	2.4	2.5	2.0
B	2.9	2.9	2.9	3.4	2.8	2.5	2.5
C	3.1	3.2	3.3	3.9	2.9	2.5	2.5
7-A	2.6	2.8	2.8	2.9	2.9	2.6	6.8
B	3.0	2.8	3.1	3.1	2.5	2.6	2.4
C	3.3	3.1	3.2	3.3	2.5	2.8	5.3
8-A	2.6	3.0	2.4	4.3	3.2	3.6	3.4
B	3.1	3.1	3.0	4.1	2.8	2.8	4.0
C	3.0	3.6	2.8	4.7	3.2	3.0	4.2
9-A	3.8	3.8	2.4	2.8	2.5	1.9	2.5
B	3.2	5.5	3.2	3.7	2.6	2.4	2.4
C	3.8	4.9	5.0	6.0	2.6	2.5	2.6
10-A	2.6	3.1	2.8	3.4	2.6	2.5	3.0
B	2.5	3.0	2.8	3.5	3.0	3.2	7.3
C	2.8	3.1	2.7	5.9	3.0	3.3	4.0
11-A	2/7	3.2	2.4	2.9	2.4	3.0	5.5
B	2.8	3.3	3.0	6.0	2.8	2.5	4.9
C	2.4	2.7	3.2	10.0	2.8	2.6	3.2
12-A	2.7	2.8	2.4	3.5	2.8	3.6	3.5
B	2.3	2.7	2.6	3.6	3.2	2.8	3.2
C	2.4	3.0	3.4	4.5	3.1	3.1	4.3

Conductivity (ECe)

Hole #	1972			1973		
	3/18	7/17	9/28	3/31	6/2	10/12
1-A	2.3	2.6	2.7	2.6	2.5	2.9
B	2.7	3.0	2.5	2.5	2.6	2.6
C	2.8	3.6	3.8	2.9	2.8	2.6
2-A	2.3	2.8	2.3	2.5	2.3	2.4
B	2.2	2.5	1.7	2.4	2.4	2.3
C	2.5	2.6	2.4	2.7	2.6	2.4
3-A	4.2	4.5	5.9	3.0	2.7	3.2
B	3.1	2.6	4.9	3.0	3.6	7.9
C	4.2	2.6	3.0	3.2	4.5	4.8
4-A	2.4	4.6	4.0	2.7	3.0	3.4
B	2.4	3.1	4.3	3.0	2.9	2.8
C	3.0	3.6	2.4	3.2	3.4	2.6
5-A	2.4	1.7	2.5	1.3	1.5	2.2
B	2.4	2.5	1.9	2.4	2.5	2.4
C	2.4	3.0	2.6	2.4	2.2	2.5
6-A	2.4	1.6	2.4	2.4	2.2	2.4
B	2.3	2.7	2.2	2.4	2.2	2.3
C	2.6	1.8	2.6	2.6	2.2	2.4
7-A	3.5	5.0	7.1	3.3	2.5	2.5
B	7.2	4.6	5.0	2.9	2.6	2.9
C	4.8	4.5	4.1	3.5	3.0	2.7
8-A	2.5	4.0	4.8	2.7	2.5	2.8
B	2.4	2.4	3.4	2.6	2.2	2.4
C	2.6	2.6	3.1	3.0	2.4	2.5
9-A	2.2	2.4	2.4	2.1	2.6	2.4
B	2.2	2.4	2.1	2.3	2.2	2.3
C	2.2	2.2	2.4	2.4	2.3	3.2
10-A	2.4	8.5	4.2	2.6	2.3	3.0
B	4.1	3.5	2.8	2.9	2.4	3.4
C	3.1	3.0	1.9	3.4	2.5	5.9
11-A	3.4	8.6	5.5	3.6	2.1	4.7
B	3.7	7.2	6.0	3.6	3.3	3.4
C	6.5	4.5	4.5	3.0	3.0	3.2
12-A	3.2	21.0	4.5	3.2	5.9	5.1
B	3.6	3.1	5.5	3.4	7.1	5.9
C	3.2	2.6	9.0	2.7	5.0	6.3